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13. ABSTRACT
This report summarizes activities on an ARPA University-Industry ATR Initiative contract to McDonnell Douglas Aerospace (MDA), with subcontracts to the University of Maryland and Summus Ltd.

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TYPE OF REPORT: FINAL PROGRESS

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1. Statement of the Problem Studied

This report summarizes efforts by McDonnell Douglas Aerospace, with Summus Ltd. (Columbia, SC) and the University of Maryland as subcontractors, on an ARPA University-Industry ATR (Automatic Target Recognition) Initiative contract from 14 November 1994 to 14 February 1997. The principal program objectives of this effort were:

- Improved detection/recognition/identification of targets in clutter,
- Increased probability of acquisition and reduced circular error probability (CEP) for autonomous weapons, and
- Fast automated reference preparation from reconnaissance imagery, made possible by 3-D site estimation from the imagery, and matching of reference information and sensed image data across spectrums. Reference imagery is not traditionally used for prosecution of time critical mobile targets because references cannot be extracted within target time cycles.

McDonnell Douglas and Summus, Ltd. investigated a variety of applications of multiresolution wavelet analysis to improve the separation of the target signature and shape from background clutter. Wavelet analyses are well-suited for efficiently representing the geometric structure in real imagery, as evidenced by the outstanding results achieved by wavelet-based approaches to image compression. Planned approaches included:

- The development of improved clutter model estimation using multiresolution wavelet analyses. These would be employed for clutter screening , providing a mechanism to reduce false alarms on background clutter regions which would otherwise yield a good match to the target.
- The development of adaptive wavelet transform techniques which are sensitive to specific features or content of an image. Examples include closed set wavelet transforms adapted to an image by partitioning along detected edges, or the wavelet packet transform which yields a richer set of coefficients from which a "best basis" may be extracted. Applications of adaptive wavelet transforms include segmentation (useful in reference preparation from reconnaissance imagery), texture analysis, and extraction of higher order statistics within partitioned regions of an image (potentially useful in the context of the MDA's General Pattern Match algorithm, which is nominally based on zeroth-order statistics).

The University of Maryland investigated the application of image understanding techniques to the problem of estimating 3-D geometries of target sites from reference imagery. This effort extended site model construction and maintenance techniques originally developed under ARPA's Research and Development of Image Understanding Systems program. The ultimate objective of this site model effort was to develop fast and automated techniques for constructing 3-D site models of target sites using reconnaissance imagery. The resulting site models could then be used to provide two alternative forms of reference: (a) the 3-D site model itself or (b) a 2-D scene rendered to the perspective of the weapon system approach on the target. The goal of accelerating and automating the site model construction process was to make target references available quickly enough to be used within time cycles for time critical targets.

2. Summary of Important Results

2.1 Summmus Ltd.

2.1.1 Target / Clutter Separation

Summus developed an algorithm for separation of targets from background clutter, using a wavelet-based oscillation measure which characterizes texture properties. This measure provides a clutter feature which can be used for target/clutter segmentation or as a decision aid for other algorithms. To provide a complete mechanism for target detection, Summus also developed a quadtree based image segmentation algorithm. The algorithm partitions an input image into homogeneous regions based, for example, on pixel intensity. The image segmentation algorithm can be applied to the image itself or it can be combined with the above target/clutter separation algorithm for automatic target recognition.

Summus evaluated the utility of the wavelet-based oscillation measure for target detection, using a limited testbed of 50 FLIR images of mobile targets in both clutter and open terrain. The algorithm was able to distinguish targets with a P_D of 97%, with a P_{FA} of 6%. In 1996, Summus extended this algorithm to target recognition and tracking in image sequences through an adaptive temporal modification of the wavelet-based oscillation measure. More detailed descriptions of these investigations and the results can be found in [2], [8], and in forthcoming manuscripts.

Summus implemented some of these algorithms on the Texas Instruments C40 digital signal processor. These implementations were to be used for evaluations in the context of MDA's General Pattern Match hardware, during the optional second phase of this program, which was not funded.

2.1.2 Feature Enhancement and Extraction

Summus also investigated two different approaches to enhance image quality for improved target recognition performance. The first approach is based on use of conventional highpass local neighborhood filters. Implementing the filters in the wavelet domain results in equal or better image enhancement when compared to typical pixel domain based applications. There is also a reduction in computational time, presuming that the wavelet transform is already applied for some other reason, e.g. compression. Details of this effort can be found in [2].

The second approach involves the use of nonlinear partial differential equation methods to solve a nonlinear diffusion equation. This approach essentially treats the current image as a blurred version of the source image. By reversing the blurring (diffusion) process, it is possible to project back to the source image. This approach operates in the pixel domain and is well suited for large levels of noise. It enhances features in the images and improves target/clutter estimation. A more detailed description of this investigation and the results can be found in [2].

In 1996, Summus extended their earlier work with nonlinear PDEs to demonstrate effective edge detection and segmentation of images in clutter. Summus also used nonlinear PDEs to enhance images which had been magnified using the wavelet transform. For magnification, the scaling filter of the wavelet transform acts as an interpolating filter, which causes the resulting image to be some-

what blurred. The blurring effect can be reduced using nonlinear PDEs. A more detailed description of this investigation and the results can be found in [8].

Summus is now working on a new resolution-independent image file format based on wavelets and nonlinear PDEs. Nonlinear PDEs will be used to estimate the source image (i.e., the "real world" scene) from which a sensed image is derived. The image content is modeled in terms of vectors of infinitely fine resolution in the wavelet domain. This format will be well-suited for compression and for image analysis (including target recognition), and will also facilitate efficient transmission and database retrieval. More details on this effort can be found in [8].

Additional details on these efforts will be provided in forthcoming manuscripts.

2.2 University of Maryland

2.2.1 Site Model-Based Image Exploitation

The University of Maryland applied image understanding techniques (originally developed under ARPA's Research and Development of Image Understanding Systems program - RADIUS) to the problem of estimating 3-D geometries of target sites from reference imagery. Using a combination of manual and automated techniques, they constructed a detailed site model of the Labadie power plant site (based on target database information provided by MDA) using approximate platform orientation parameters, and registered two optical image sequences to the Labadie site. They carried out image resection using a set of identified control points, and have constructed a site model including the main buildings and functional areas. Their approach uses constrained optimization techniques for the semi-automated construction of prototypical objects. A detailed report of this effort can be found in [1].

The ultimate objective of this site model effort was to develop fast and automated techniques for constructing 3-D site models of target sites using reconnaissance imagery. The site model could then be used to provide two alternative forms of reference: (a) the 3-D site model itself or (b) a 2-D scene rendered to the perspective of the weapon system approach on the target. These forms of reference were to be evaluated in the context of MDA's General Pattern Match algorithm during the optional second phase of this program, which was not funded.

2.2.2 Dynamic Registration of Sensor Imagery to Site Models

The University of Maryland developed methods for fast, on-line, dynamic site model registration of IR image sequences to existing site models. This effort built upon the site model construction capability described above. The dynamic image to site model registration approach involves the rendering of a reference image from the site model to the approximate viewing perspective of the sensor. Then the sensed image is registered to the rendered reference image. The dynamic registration may be used in the terminal guidance of a weapon against a fixed land target, or may be used to provide rapid updates to existing site models with live sensor imagery. Details of this effort are given in [5].

2.3 McDonnell Douglas

2.3.1 Extraction of Higher Order Target / Clutter Statistics Using Wavelets

McDonnell Douglas investigated the use of wavelet subbands for extraction of higher order statistics from sensor data, for potential use in the detection of targets in clutter. This investigation was conducted in the context of MDA's General Pattern Match (GPM) ATR algorithm, which bases its target decisions on likelihood scores computed from zeroth order pixel statistics (histograms), extracted within regions of a hypothesized target templates applied to the sensed image data. Because the zeroth order analysis is invariant to spatial redistributions of pixels within a region, this approach is insensitive to texture within a region, to the internal structure of a region, and to clutter characteristics.

Because joint higher order distributions are computationally prohibitive and also would be too sparsely populated to produce a meaningful statistic, we investigated the use of wavelet transforms to reduce the joint random distribution to a distribution of a single new random variable. A 2-D wavelet transform was applied to sensed target imagery, and the resulting subbands were processed with the GPM algorithm, using a generic target detection template (used for detecting mobile targets in clutter). Unfortunately, the use of wavelet subbands to extract higher order statistics did not improve performance beyond that obtained using zero order statistics. This was found to be attributable to the interaction of wavelet filters with the target boundaries. A more detailed description of this investigation and the results can be found in [3].

2.3.2 Use of Wavelets to Extract Structural Features from Images

McDonnell Douglas investigated the use of wavelets to extract local feature points to be used for matching 2-D and 3-D structure in multiple images. Feature values were computed at each pixel location as a function of wavelet coefficients associated with the location. The feature values were thresholded to isolate dominant feature points. Where feature points were clustered, the cluster of feature points was replaced by the centroid of the cluster. Corresponding points in consecutive images of a FLIR image sequence were successfully identified using a local search technique. Details of this effort are given in [7].

3. Publications and Technical Reports

The publications, technical reports, and interim progress reports produced under this contract are listed in the References section. In addition to these papers, Summus, Ltd. is preparing two papers based on their work under this contract. Manuscripts and reprints of theses papers will be submitted when they are available.

4. Scientific Personnel

McDonnell Douglas Aerospace: Rich Peer, Jim Meany, Steve Schwartz, Chris Martens, Steve Wright

Summus, Ltd.: Björn Jawerth

University of Maryland: Rama Chellappa, Qinfen Zheng, Chandra Shekhar, Philippe Burlina, Azriel Rosenfeld

Honors, Awards, and Degrees: None. Participants are post-docs, faculty, and industry personnel.

5. Reportable Inventions

None of the software or algorithms developed on this program were considered to be reportable inventions.

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